I. C. 6795 JUNE 1934

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

MINING LIMESTONE BY A CAVING METHOD AT CRESTMORE MINE OF THE RIVERSIDE CEMENT CO., CRESTMORE, CALIF.

REGE
AUG
O. S. U.

BY

C. A. ROBOTHAM

I.C.6795
June 1934

INFORMATION CIRCULAR

UNITED STATES BUREAU OF MINES

MINING LIMESTONE BY A CAVING METHOD AT CRESTMORE MINE OF THE RIVERSIDE CEMENT CO., CRESTMORE, CALIF.[1]

By C. A. Robotham[2]

- - o - -

INTRODUCTION

The following paper describes underground mining practices of the Riverside Cement Co. of Los Angeles, Calif., in the Stanley limestone deposit at Crestmore, Riverside County, Calif. It is one of a series of papers being prepared for and published by the United States Bureau of Mines on mining methods and costs in the various mining districts in the United States.

ACKNOWLEDGMENTS

Acknowledgment is made of the assistance received from E. D. Gardner, supervising engineer of the United States Bureau of Mines Experiment Station, Tucson, Ariz., in connection with the preparation of this paper and of the cooperation of John Treanor, president of the Riverside Cement Co. Valuable assistance in developing the mining methods was obtained from a study of similar practices in the copper-mining districts of Ray and Globe-Miami, Ariz.

HISTORY

For a number of years before this project was begun, the Riverside Cement Co. had been obtaining raw material for its cement mill at Crestmore by surface mining. Underground mining had not been considered possible in this district for the recovery of cement materials, as it was considered that the deposits did not extend to depth; and even though assumptions might have been made that they be continued underground no method of extraction had been developed which was commercially feasible. The demonstration that limestone can be mined at low cost by a caving method constitutes a new departure in mining practice, and as far as known the method used at Crestmore is not employed elsewhere in mining nonmetallics.

---

[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S.Bureau of Mines Information Circular 6795."

[2] One of the consulting engineers, U.S.Bureau of Mines, and mine superintendent, Riverside Portland Cement Co., Crestmore, Calif.

Surface limestone deposits of considerable extent are owned by the company, but those directly adjacent to the cement mill were no longer suitable for economical mining by opencut methods.

The success that had been attained by caving methods in the Ray and Globe-Miami districts of Arizona, upon copper deposits of thickness similar to that of the Stanley limestone bed indicated that underground mining should be feasible at this deposit, if it was continuous below the surface. As the deposit is directly adjacent to the present mill, transportation costs of raw materials from the more distant surface reserves of the company would be eliminated. Therefore, a mining program was considered that would fulfill the maximum requirements of the cement plant on the basis of operating two 8-hour shifts.

No underground development work had been pursued in the beds of limestone adjacent to the mill before present mining operations were begun; neither had any prospecting work been conducted, other than that required for surface operations. However, surface indications and the geology of the deposit as progressively disclosed by quarrying showed that the limestone might be continuous for a considerable depth below the surface. This assumption would have to be proved by diamond drilling before the mining project was actually undertaken.

GEOLOGY

Quarrying had indicated that two beds of metamorphosed and recrystallized limestone existed in the vicinity of the cement plant; both appeared to be susceptible to mining by a caving method. (See fig. 1.)

The two beds are separated by a body of intrusive rock thick enough to allow the larger and lower bed to be mined for a considerable number of years without interfering with later extraction of the upper and smaller bed.

From surface indications it appeared that both deposits dipped slightly north of east at an angle between 45° and 55°. The larger deposit, called the Stanley bed, had been shown by surface operations to be approximately 270 feet thick at right angles to the dip. It had been uncovered for over 1,600 feet in the surface quarry. The limestone is coarsely crystalline, generally white, and suitable for the manufacture of cement. The hanging and footwalls of the limestone beds are a coarse-grained, gray, quartz granodiorite or granite of texture suitable for mining operations and of a chemical composition that makes both materials ideal for supplying the necessary "clay" element for blending with limestone in the manufacture of cement.

All limestone deposits in this vicinity undoubtedly are remnants of what was once an extended mass, which has been broken up by igneous intrusions, raised and tilted to various angles, faulted, and later eroded by surface agencies. In general, the beds or lenses of limestone are regular in formation, with their greatest thickness at their centers. From surface indications they appeared to taper to blunt points on the strike at the ends of the uncovered areas. They were later proved to continue on the dip underground.

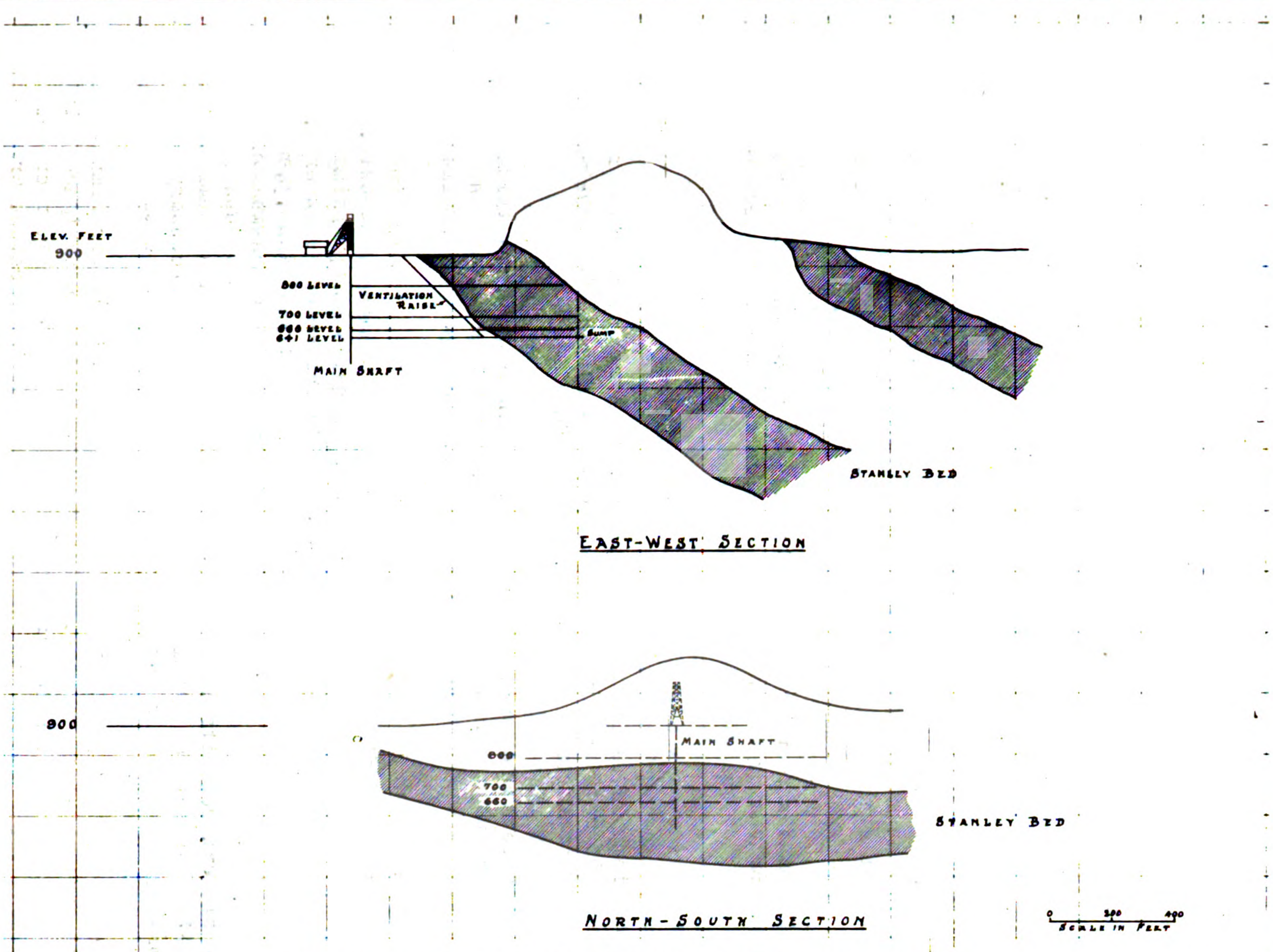


FIGURE 1.– SECTIONS THROUGH LIMESTONE DEPOSIT.

The Stanley bed, as uncovered at the surface, is fissured by minute watercourses and slightly faulted and fractures, apparently as a result of intrusions in this area. It was believed that if the larger massive blocks in the deposit were as brittle as the surrounding material, the deposit would be suitable for mining by a modified block-caving system; and that the quantity of broken and fissured material would be continually increased by the crushing action created by caving. It was assumed that this crushing action would fracture the part of the deposit that appeared upon first observation to be massive.

PROSPECTING AND SAMPLING

The location of the deposit, together with surface operations which had been pursued for a number of years, allowed a prospecting program by diamond drilling that would obtain enough information for conclusive determination with a minimum of work. Wherever conditions would allow, vertical diamond-drill holes were located and drilled according to a coordinate system that had been laid out covering the deposit.

The Stanley bed was found by diamond drilling to be continuous in a north and south direction, terminating at each end in a blunt formation, as surface indications intimated. This bed appeared to flatten at greater depth, increasing slightly in thickness. Further diamond drilling east of the surface workings proved that both the upper and lower deposits were uniform and continuous in the direction of the dip. Samples obtained from this diamond drilling furnished information as to the quality of the deposits, which was found to be satisfactory for manufacturing cement. In general, the core recovery was satisfactory; and where the core was lost due to the friable nature of the material being drilled, it was assumed that the missing core was pure limestone. This assumption has been checked closely from underground operations and found to be correct to date. No sludge samples were obtained during drilling due to the porosity of the limestone and consequent loss of water and drill cuttings.

Since the commencement of mining underground a rotating long-hole drill has been used for prospecting to determine contacts, to prove deviations in the direction of the deposit, and to obtain samples. This drill is mounted on a special shell and uses 1-1/4-inch-diameter hollow-round steel upset to 1-1/2 inches at the threaded couplings; it has a special water connection in front of the machine to provide water for drilling. It has been found possible with this equipment to drill holes in any direction exceeding 100 feet in depth. The chief disadvantages in the use of this drill are the loss of cuttings due to the formation being porous and to the fact that the rock being drilled may be so abrasive that the clearance of the drill is lost before much advance is attained.

ESTIMATES OF MATERIAL IN PLACE

As diamond drilling progressed the information obtained was plotted on both horizontal and vertical sections, the latter running north and south and east and west. These sections disclosed that the two beds of limestone were apparently continuous in all directions within the limits of the beds, and showed that the Stanley deposit increased in thickness and length at lower elevations.

A tentative layout of the proposed mining method had previously determined that the first extraction elevation would be approximately 185 feet below the surface or old quarry floor. Calculations of the material above this elevation were made from samples obtained from diamond drilling, by dividing the area into sections 100 feet square, determining an interpolated value at all the four corners of the respective squares from adjacent drill holes, and then using these four values to determine the value of the material in the block so formed. Each block had a base of 100 feet square and was approximately 185 feet high. The sum of these individual calculations indicated the quality and quantity of the material above the elevation referred to suitable for the cement plant.

Similar calculations were continued to cover the deposit to a second and lower mining elevation; these showed that a much larger tonnage was available in the next lift to be extracted of approximately the same quality as indicated by the first set of calculations and likewise suitable, for the manufacture of cement.

By this method of calculation it was possible in the early stages of the engineering program to determine the value of any section to be mined. Thus if there were any possible change in the grade of material the first section to be mined could be selected of such a grade as would offer no possible chemical difficulties. Although it was anticipated before mining operations were begun that enough production could be obtained from the first caving block to fulfill the requirements of the cement plant at an economical cost, no previous mining practices were available to prove this.

The calculations have checked closely so far, with the results obtained from samples taken according to regular procedure from development drifts, raises, cut-off stopes surrounding the block, and from undercut stoping work at the bottom of the block - all of which are used further to check the value of the actual area mined.

Grab samples of development work are unnecessary, as the demarcation between the hanging-wall or footwall materials and the limestone is so clear that it is unnecessary to determine other than by eye the class of material encountered.

In manufacturing cement a certain amount of "clay" is required to blend the limestone to the proper composition. At Crestmore, as stated before, the hanging-wall and footwall materials are of ideal composition for this purpose. This condition allows utilization of material obtained from development in the wall rock.

The limestone in the Stanley bed requires more than 10 percent clay material for blending to the correct composition for manufacturing cement; and as the hanging wall constitutes ideal clay material for this limestone, it was

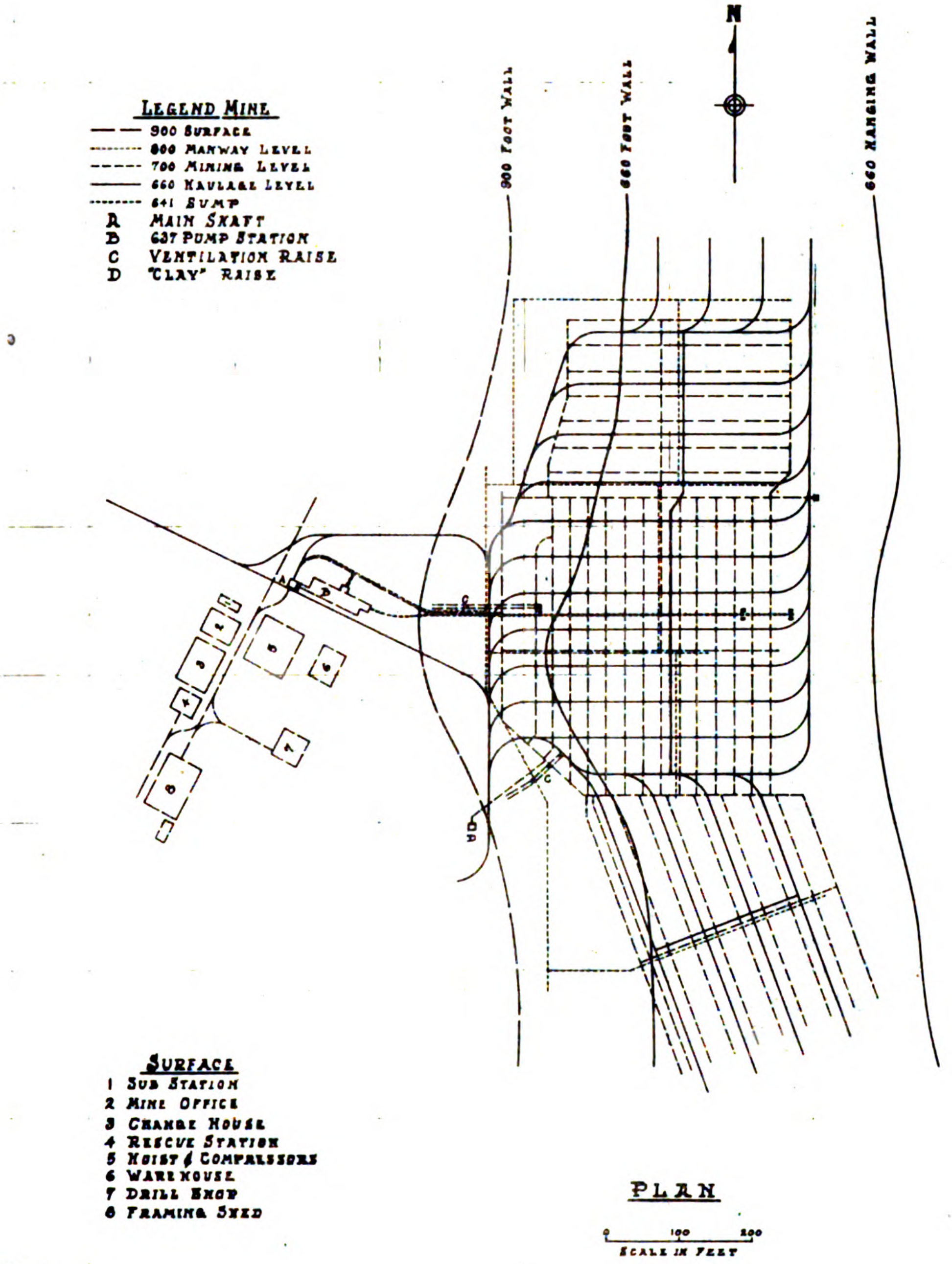


FIGURE 2.- MINE DEVELOPMENT PLAN.

Original from THE OHIO STATE UNIVERSITY

reasonable to assume that until such time as the dilution from hanging-wall caving exceeded the blending requirements, the admixture obtained from normal operations would be an advantage rather than a disadvantage. This condition would be different if the surrounding rock were valueless in the manufacturing process, which is generally the case in mineral deposits.

No considerable admixture of hanging-wall material was expected, as the cubical fracture of the crystalline limestone in this deposit would appear to prevent the formation of funnels in the broken rock during extraction operations. Moreover, the irregular angular shapes of the broken fragments of limestone also would tend to prevent the infiltration of finely divided hanging-wall material unless the angle of repose of the finely divided material on these fragments is exceeded. It may then descend if funneling occurs above a draw point. Nevertheless, the problem of dilution was initially serious because of the possibility that the quantity of dilution obtained with the production might render the average lime content in the mine-run output too low for manufacturing cement.

METHOD OF DEVELOPMENT AND MINING

Before any underground development was started a mining scheme had been designed closely following the methods that had proved successful in Arizona, and practices were adopted which had proved satisfactory under conditions similar to those that were believed to hold at this deposit.

It was realized that for economical results an efficient transportation system with a capacity suited to the normal requirements of the cement plant should be installed. Such a system embraces efficient methods for loading and unloading, and cars of correct design. Based on these requirements, a combination of 1 locomotive and 14 five-ton cars was proposed as a transportation unit.

The mining scheme as developed (see fig. 2) called for the haulage level to be located far enough below the actual points of extraction to permit pockets or raises of sufficient size to hold enough material to fill the 14 cars of a transportation unit from one loading point on the haulage level. This consideration placed the transportation system some 55 feet below the extraction limits of the first section to be mined. The mining or extraction level was located 15 feet below the extraction line and a manway level for entrance to working places, ventilation and handling of supplies was driven approximately 100 feet below the surface.

The three levels referred to were so designed that they would serve the entire upper section of the deposit which had been proved by diamond drilling, only such development being destroyed by the completion of extraction operations as was directly applicable to that section.

Diamond drilling had disclosed that the deposit was waterlogged, with indications that the water supply was subterranean. Further investigation also suggested that there was no connection between the water in the limestone and that in the surrounding territory. The fact that the limestone contained water had to be considered in all development schemes. A sump drift and pumping equipment were located far enough below the proposed mining operations to drain sufficient of the deposit to prevent the water from interfering with mining operations. The pump station was designed to be accessible at all times, irrespective of the elevation of the water during development and future operations.

Ventilation facilities, together with the second entry required by California law, were designed as a unit and located in the footwall. These were used in the early stages of development as a means of entry to the sump drift before the deposit was unwatered.

It was decided to begin development by sinking a main shaft (see fig. 3) at a point chosen after considering the inferences that could be drawn from the sections and plans made in determining the character and extent of the deposit; the requirements of the proposed mining method; the physical conditions of the surface; and the relation of the delivery point of mined material to the cement plant.

Sufficient of the material surrounding the deposit had been removed by open-cut operations to allow the shaft to be placed far enough from the footwall-limestone contact at the surface that mining operations would not jeopardize any of the buildings and surface equipment that was necessary for the pursuance of the underground work.

The axis of the main shaft was placed to allow development of an efficient underground haulage system in the footwall of the deposit, so that the main hoisting skips would discharge into a receiving bin from which the material could be conveyed directly to the mill crushing plant.

Main Shaft

The proposed mining system, with such information as had been obtained from prospect drilling in the lower portion of the deposit, indicated that one main hoisting shaft could economically serve production requirements of the cement plant for a number of years.

The shaft design was developed to accommodate all facilities for handling production, as well as men and supplies. The shaft, concreted throughout its entire length, has five compartments (see fig. 4). Two compartments are used by the limestone-hoisting skips operating in balance. One large compartment on the west side accommodates the man-material elevator which is of the self-leveling, full-automatic type. A fourth compartment is used for a manway and contains the main air lines, steel ladders, and platforms mounted on precast concrete beams. A fifth compartment contains the main pump-discharge columns from the underground pump station.

This shaft was so located as to allow for the installation of underground storage pockets of the haulage system as designed and that the material from the receiving bins could be drawn directly onto a conveyor belt to the existing mill crushing plant.

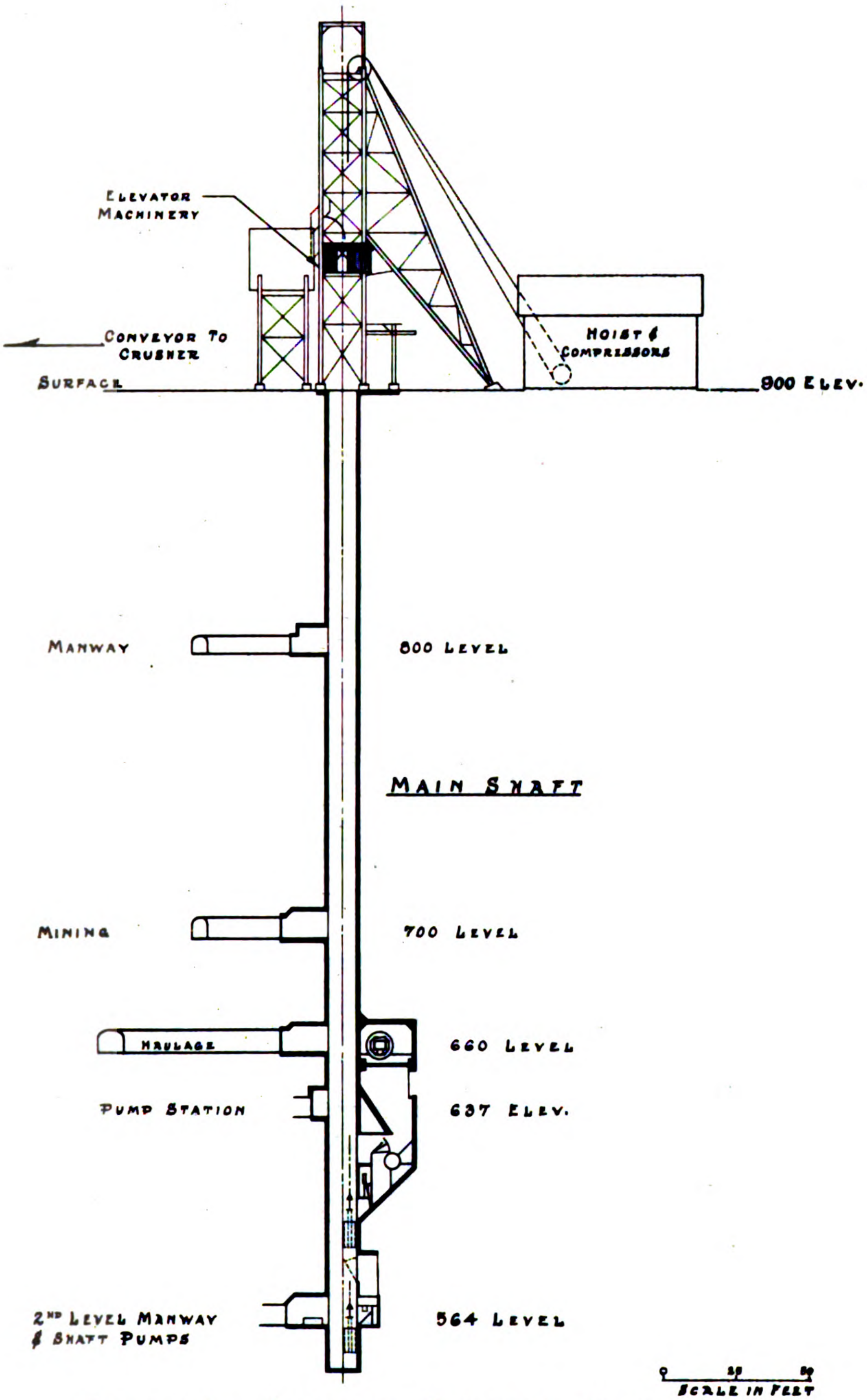


FIGURE 3.- SECTION THROUGH MAIN SHAFT.

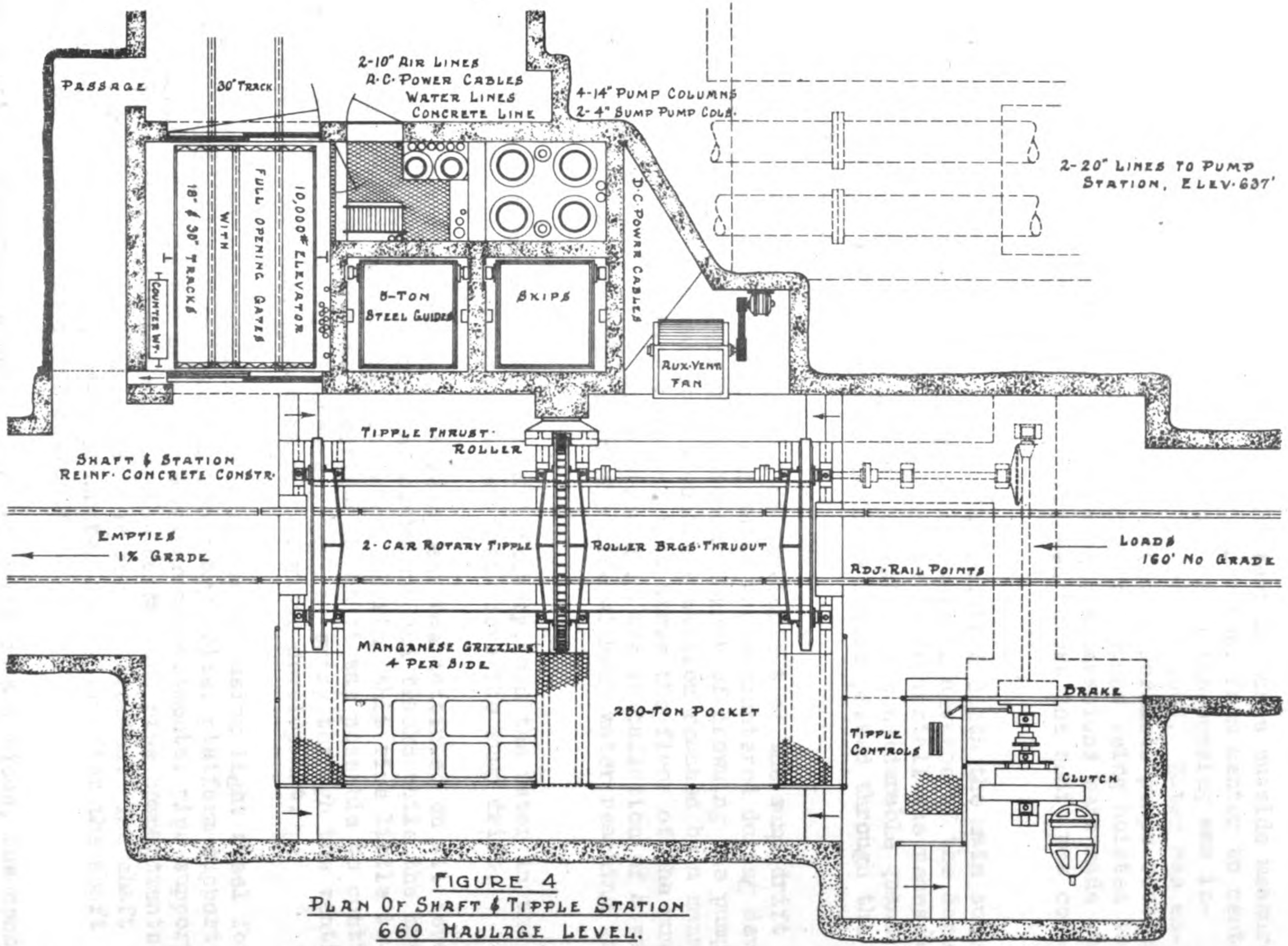


FIGURE 4
PLAN OF SHAFT & TIPPLE STATION
660 HAULAGE LEVEL.

A steel headframe was contemplated over this shaft, in which machinery for operating the automatic elevator and a skip-dumping mechanism of modern design, would be installed.

The shaft was sunk 11 feet 0 inches by 20 feet 3 inches outside measurement. Timbers 10 by 10 inches were used, spaced 5 feet from center to center until the more massive formations were reached. Then the spacing was increased to 7-1/2 feet to reduce the quantity of lumber used. Water was encountered after the first 100 feet and was handled by portable pumps resting directly on the muck at the bottom of the shaft, the pumps being hoisted to the surface when blasting. As sinking progressed, excavations were made at the different levels to allow drifting to proceed before the shaft was concreted.

As soon as the shaft had been sunk to the required depth the main sump drift was started toward the limestone and kept well in advance of the development on the upper levels. It was deemed advisable to install the necessary pumping equipment to drain the water, known to exist in considerable quantity in the porous limestone, before any intermediate levels passed through the footwall contact into the limestone.

The pumping equipment and the method of development of the sump drift were such that if an excessive quantity of water was encountered during development it could be handled successfully without danger of drowning the pumps. The pumps were installed in a watertight concrete station reached by a manway and small elevator from the mining level 63 feet above the floor of the pump station. The entry at this point was protected by the installation of a watertight door which would allow flooding of the mine without water reaching the pumps.

The pumping system proved entirely satisfactory, and the water in the limestone was lowered to an elevation a few feet above the sump drift.

As soon as this was accomplished development was continued on all levels to allow installation of the underground equipment and tracks while the main shaft and loading pocket were being concreted. During this time little interruption to underground work was experienced, as it was possible to continue mechanical, electrical, and other necessary work by entry through the ventilation raise that had been used as a part of the water development.

The main shaft was concreted from the bottom up, using light steel forms in which were provided locations for all necessary bolts, platform supports, guide attachments for both the skip and elevator compartments, pipe supports, and the precast concrete dividers used in the manway and pipe compartments - all of which were standard in each section of form as erected. The shaft stations at the different levels were concreted before or after the shaft lining had been completed, as found convenient.

The hoisting compartments were concreted solid on all sides, the concrete divider wall being provided with breather holes behind the guides to prevent excessive pumping of air during hoisting. The purpose of concreting the hoisting compartments solid was to reduce possible damage to a minimum if an accident should occur to one of the main skips.

As the manway compartment is adjacent to the large compartment containing the elevator an emergency exit from the elevator was provided through internally locked doors, reached either from the car itself or from an extension ladder on top of the car.

Steel and concrete construction was used throughout, to make the main shaft completely fireproof, as it is an intake unit in the ventilation system. Steel guides were used for all hoisting equipment; steel ladders and platforms were provided in the manways, together with steel power-cable and pipe supports; and precast concrete dividers were used between the manway and pipe compartments, serving to rigidly connect the hoisting compartments with the other sections of the shaft.

The installation of a full-automatic, self-leveling elevator in this shaft, of sufficient size and capacity for handling all men and material required, is considered an innovation in mine equipment. Operations to date have justified this departure from orthodox mining methods.

As soon as the shaft was concreted erection of the steel headframe was begun. In this structure, provision was made for the elevator equipment and also for small sheaves at a convenient height to allow development to proceed before the entire structure was completed; such sheaves were to be used later for shaft repairs or inspection, if necessary.

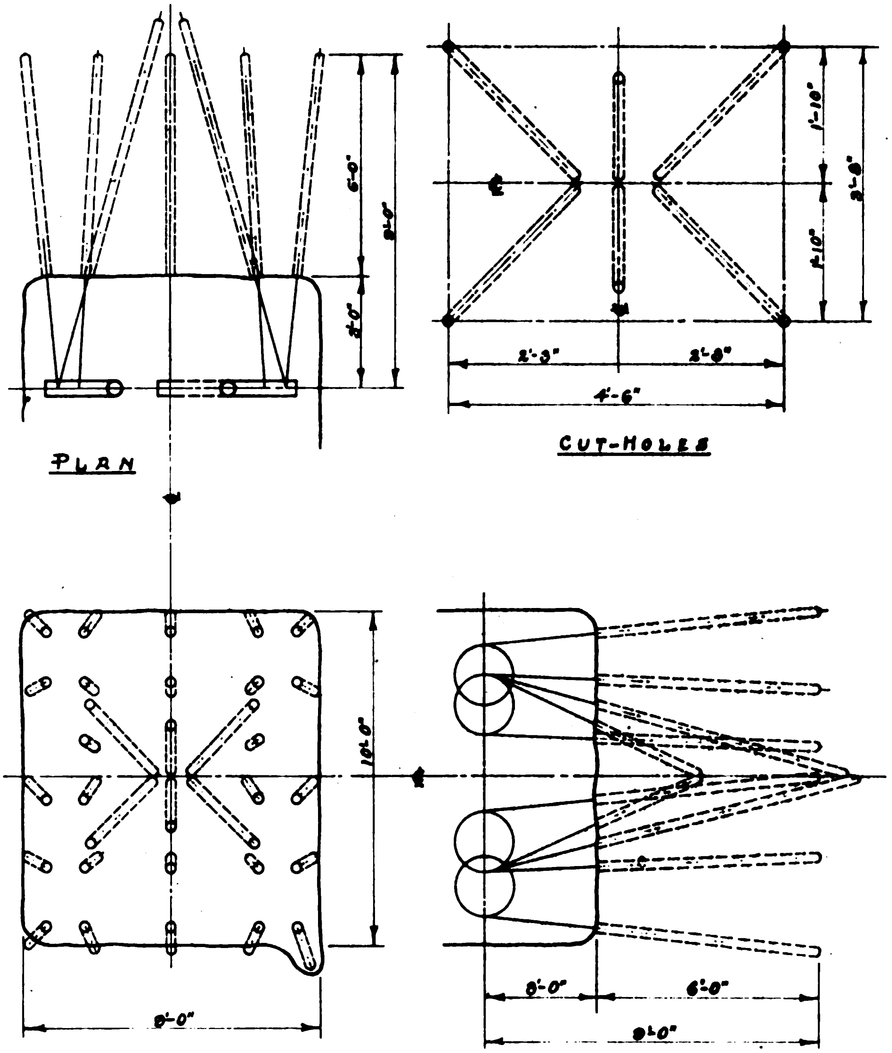
Completion of the pocket, tipple station, and loading equipment (see fig. 4), with work on the other levels, was pursued by using auxiliary equipment during the erection of the headframe and completion of the large hoisting equipment.

As the granite at the pocket was found to be faulted the tipple station excavation and concreting were completed first, being supported on massive concrete beams designed as a part of the main shaft and the back wall of the pocket. Excavation for the pocket was made by working from the tipple station down, such material as was obtained from work in the mine being handled by an auxiliary slide at the top of the excavation.

The loading equipment as designed and installed is considered novel. Such fine material as may be lost during loading operations is recovered from a spill pocket below the skip-loading station, the spilled material being hoisted once or twice a week, as necessity requires.

Haulage Drifts

Underground transportation facilities to some extent governed the size of the haulage drifts. It was considered feasible and economical to use a trolley system as a means of motive power. The use of this equipment was considered favorably because little supporting timber is required in the drifts, the


PLAN

CUT-HOLES

FIGURE 5
STANDARD 32-HOLE ROUND
FOR 9'x10' MOTOR DRIFT.

loading chutes are spaced 25 feet apart and can be provided with additional safety features if found necessary, and mining operations should not impair the safety clearances.

The trolley-haulage system further governed the size of the haulage drifts, as the California law requires a trolley wire placed at the side of a drift to be at least 3 feet from the center line of the track and 7 feet above the rail. The size of the drifts, determined by these limitations, fitted in nicely with the haulage equipment proposed.

The trolley wire in each haulage drift is energized automatically by the entry of a transportation unit, providing an additional safety feature for men working in each drift on operations other than production.

The size of the haulage drifts is standard throughout, whether in the granite footwall or in the limestone. It has been unnecessary, except in faulted areas, to use supporting timber for any of the drifts. All haulage drifts are 9 feet wide by 10 feet high and are driven by a standard method of excavation. The standard round used is illustrated in figure 5. These drifts thus have ample clearance for safe operation of all haulage equipment.

Mining Drifts

Smaller drifts are driven on the mining and manway levels, varying in size according to their use. Permanent drifts serving an entire level and driven in the footwall are approximately 5 feet wide by 7 feet high, allowing ample room for pipe lines and equipment for mining. Drifts directly pertaining to an individual section, for drawing operations, are driven somewhat smaller in an endeavor to minimize damage from extraction operations.

As a general rule, it is unnecessary to use timber at the points of extraction; but if the ground is friable at any point, timber may be required for maintaining the size of the extraction opening. Recent development has proved that the use of concrete in place of timber has materially reduced maintenance costs in connection with drawing operations.

Raises

In the early stages of mine development it was desired to drive raises approximately 4 feet square, which was found to be difficult as the tough nature of the ground necessitated correctly spaced cut-holes in all blasting operations. The size of the raises was consequently enlarged to allow for proper cut-holes to be drilled with the class of machines used for this work.

Storage raises between the haulage and mining levels are driven by using stulls for temporary platform supports for drilling. Manway raises for stoping operations and transfer raises in excess of 30 feet can be driven more economically by dividing the raise into two compartments and drilling off the broken muck in the rock compartment. The use of two compartments also affords an added safety factor in this work.

Mining

Limestone has been recovered by different underground methods of mining in many parts of the country; but, as mentioned before, it had not been mined by a caving method.

The caving method described herein is an innovation in the mining of limestone, although it has been used for some time in mining copper and other metallic ores. The caving systems employed all follow more or less the same general method, with modifications to suit the nature of the particular deposit being mined. Such methods, in most cases, were developed in ground apparently more suitable for caving method than this limestone deposit. However, surface indications showed that the limestone was fissured to some extent by minute watercourses, and diamond drilling proved that these water fissures also existed at a considerable depth. The limestone, although hard, is brittle and badly broken by displacement. These facts indicated that if a section could be separated successfully from the surrounding material the limestone should cave with satisfactory results.

The underground scheme laid out for the Stanley deposit was patterned after the caving methods used at certain copper deposits in Arizona, with modifications considered advisable to adapt them to this particular deposit. The scheme divided the bed into panels 200 feet in a north and south direction and the width of the deposit in an east and west direction; such panels were again divided into blocks requiring, as near as it was possible to estimate, an equal amount of development work for each block.

The method of mining was to separate each block from the adjacent material by the necessary number of shrinkage cut-off stopes and then undermine the bottom of each block by a series of small undercut stopes and pillars. In general this scheme was similar to the so-called "Sub-level, undercut caving" method[3] used by the Nevada Consolidated Copper Corporation at Ray, Ariz., with modifications to suit the size of the block mined and the class of material.

Other methods of mining had been studied but were considered not so desirable as the method finally adopted and used since underground operations were begun. The method adopted has been subjected to minor modifications as the work progressed, all tending to increase the efficiency of operations pursued during the actual breaking process and also to improve the extraction operations.

The first block of limestone to be mined was served by four haulage drifts on 50-foot centers (see fig. 6) with loading chutes spaced every 25 feet and extending throughout the minable area in an east and west direction. These haulage drifts were driven well in advance of the mining level development 40 feet above, so that disposal of the material from the upper-level workings could be handled by gravity.

---

[3] Thomas, Robert W., Mining Practices at Ray Mines, Nevada Consolidated Mining Co.; Inf. Circ. 6167, Bureau of Mines, 1929, 27 pp.

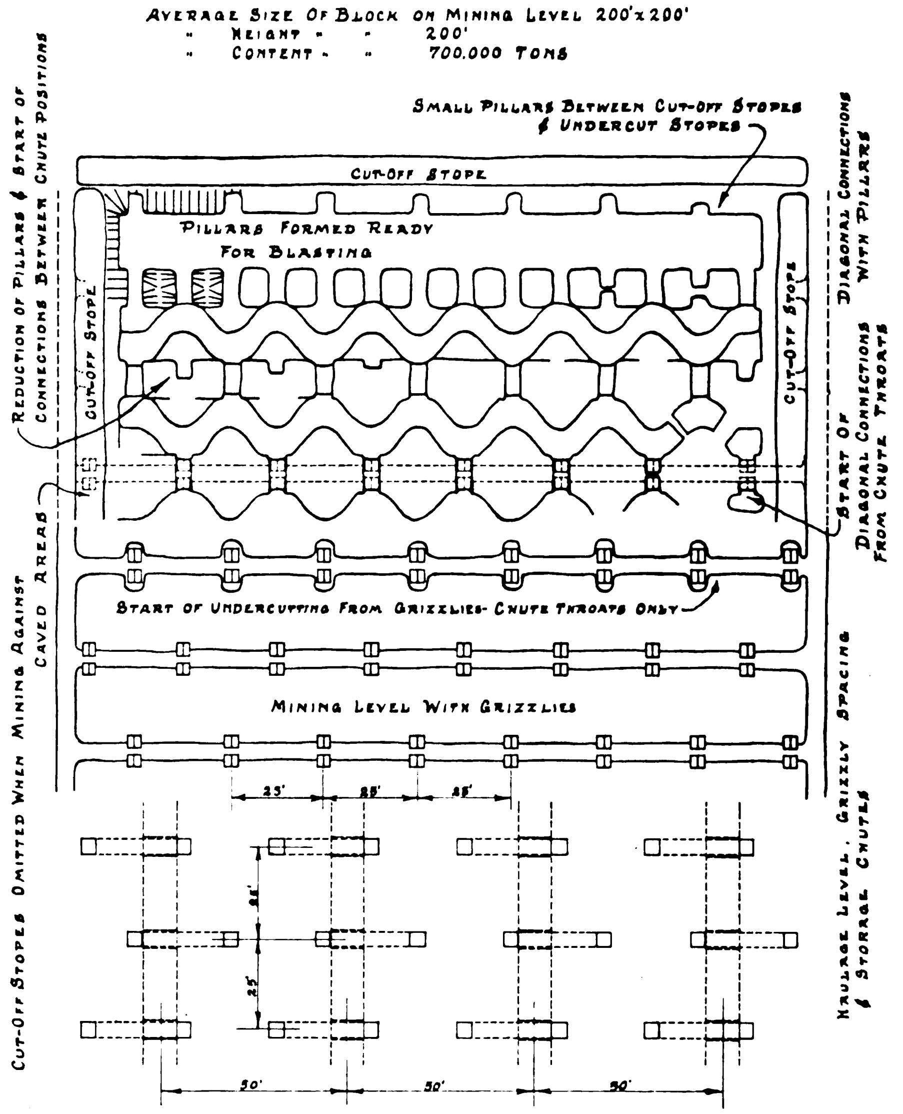

AVERAGE SIZE OF BLOCK ON MINING LEVEL 200'x200'
" HEIGHT " " 200'
" CONTENT " " 700,000 TONS
SMALL PILLARS BETWEEN CUT-OFF STOPES & UNDERCUT STOPES
CUT-OFF STOPE
PILLARS FORMED READY FOR BLASTING
CUT-OFF STOPE
CUT-OFF STOPE
REDUCTION OF PILLARS & START OF CONNECTIONS BETWEEN CHUTE POSITIONS
DIAGONAL CONNECTIONS WITH PILLARS
START OF DIAGONAL CONNECTIONS FROM CHUTE THROATS
CAVED AREAS
START OF UNDERCUTTING FROM GRIZZLIES- CHUTE THROATS ONLY
MINING LEVEL WITH GRIZZLIES
CUT-OFF STOPES OMITTED WHEN MINING AGAINST
GRIZZLY SPACING
HAULAGE LEVEL, & STORAGE CHUTES
25'
25'
25'
25'
25'
50'
50'
50'

FIGURE 6
PLAN OF
UNDERCUT CAVING METHOD No. 1.

0 20 40
SCALE IN FEET

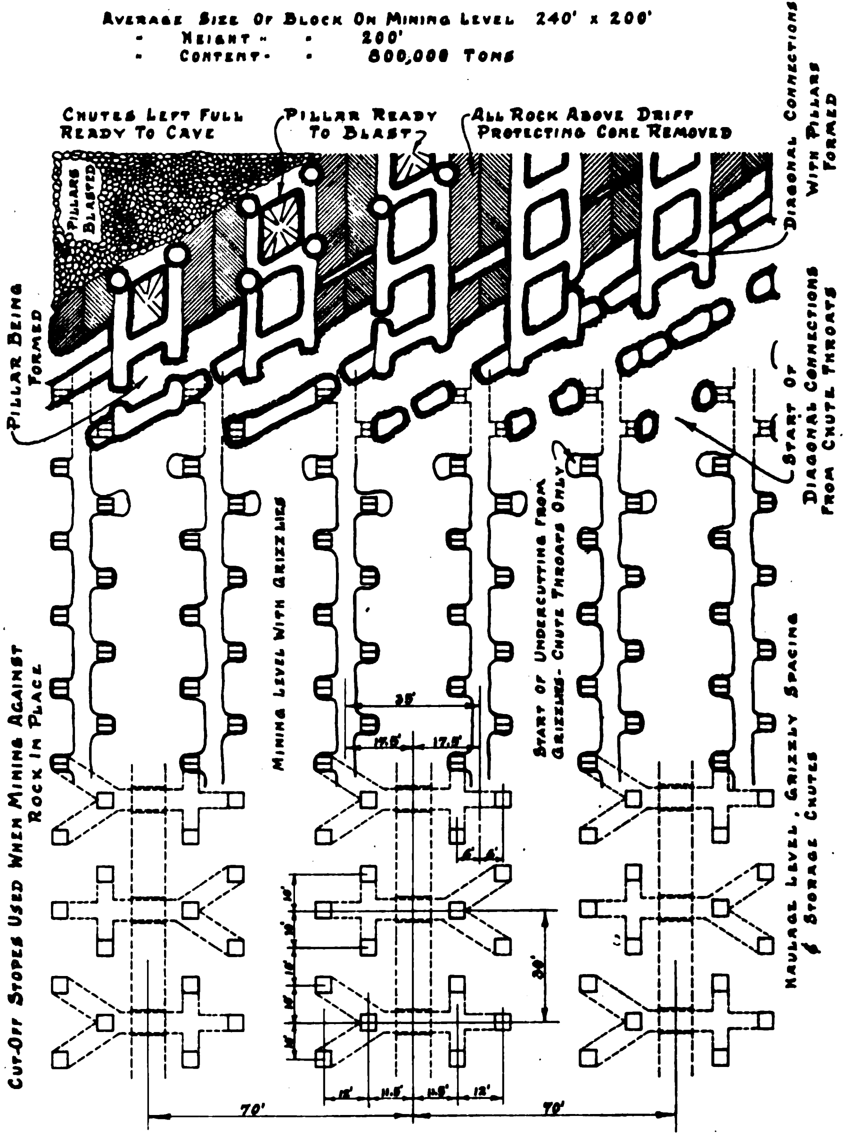
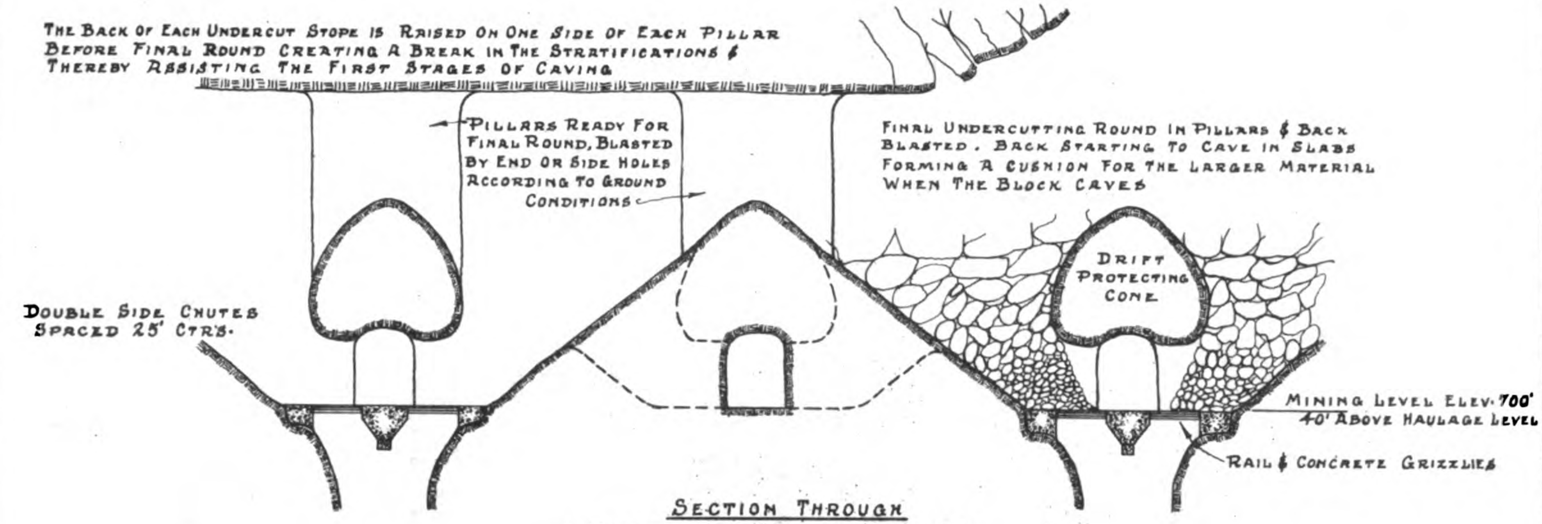

Average Size Of Block On Mining Level 240' x 200'
" Height " " 200'
" Content " " 800,000 Tons
Chutes Left Full Ready To Cave
Pillar Ready To Blast
All Rock Above Drift Protecting Cone Removed
Diagonal Connections With Pillars Formed
Pillars Blasted
Pillar Being Formed
Start Of Diagonal Connections From Chute Throats
Start Of Undercutting From Grizzlies - Chute Throats Only
Mining Level With Grizzlies
Cut-Off Stopes Used When Mining Against Rock In Place
Haulage Level, Grizzly Spacing & Storage Chutes
35'
17.5'
17.5'
6'
6'
30'
10'
10'
10'
10'
10'
12'
11.5'
11.5'
12'
70'
70'

FIGURE 7
PLAN OF
UNDERCUT CAVING METHOD NO. 2


The Back of Each Undercut Stope is Raised on One Side of Each Pillar Before Final Round Creating a Break in The Stratifications & Thereby Assisting The First Stages of Caving
Pillars Ready For Final Round, Blasted By End or Side Holes According to Ground Conditions
Final Undercutting Round in Pillars & Back Blasted. Back Starting to Cave in Slabs Forming a Cushion For the Larger Material When The Block Caves
Double Side Chutes Spaced 25' Ctrs.
Drift Protecting Cone
Mining Level Elev. 700' 40' Above Haulage Level
Rail & Concrete Grizzlies

SECTION THROUGH
UNDERCUT CAVING METHOD NO. 1

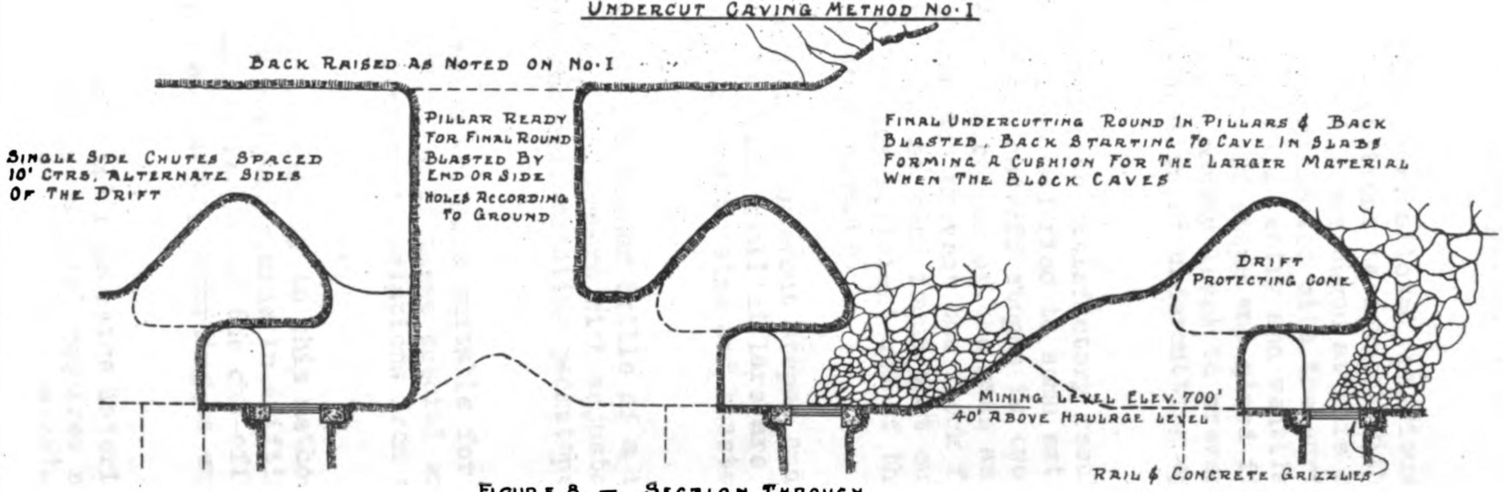

Back Raised as Noted on No. 1
Single Side Chutes Spaced 10' Ctrs. Alternate Sides of The Drift
Pillar Ready For Final Round Blasted By End or Side Holes According To Ground
Final Undercutting Round in Pillars & Back Blasted. Back Starting to Cave in Slabs Forming a Cushion For the Larger Material When The Block Caves
Drift Protecting Cone
Mining Level Elev. 700' 40' Above Haulage Level
Rail & Concrete Grizzlies
0
5
10
Scale in Feet

FIGURE 8. — SECTION THROUGH
UNDERCUT CAVING METHOD NO. 2.

The mining-level drifts running north and south, or at right angles to the haulage drifts below, are spaced 25 feet apart, with raises driven every 25 feet connecting with the loading chutes below. These raises are alternately driven vertical and inclined, thus staggering the draw points on the mining level in adjacent drifts.

As soon as drifting development on the mining level allowed, previously driven manway raises were completed in the stope positions to connect with the manway level 100 feet above. Before shrinkage stoping was begun at this elevation, other previously driven manway raises were connected with the surface or to a small level at the 900-foot elevation to furnish entry and ventilation to each shrinkage stope. The upper half of the cut-off stope was mined first, allowing a pillar to remain at the elevation of the manway level to prevent the block of limestone caving as a unit upon completion of undercutting operations.

The first block was mined by the above method with satisfactory results; but in mining subsequent blocks, the method has been modified to some extent (see fig. 7). It was found unnecessary to work the cut-off stopes in two lifts, because enough limestone broke away from the bottom of the mass as undercutting progressed to fill the undercut area and prevent the block from caving as a unit. As a result of work to date, it has been found that cut-off stopes should only be driven wide enough to allow for efficient use of the explosive required to obtain an economical vertical advance.

Undercutting has been developed from a system of undercut stopes and pillars to a room-and-pillar system (see fig. 8) in which small pillars are left in the undercut areas between the drifts to be reduced in size and blasted out as the undercutting progresses.

The mining that has been described is done with leyner drills of a type commonly employed in large tunnel work. Mounted jackhammers with adjustable shells are used for drifting in small tunnels and self-rotating jackstopers in the cut-off and undercutting operations.

Special explosives have been developed, which are more suitable for the rock being mined than grades in general use. The use of these special explosives and that of concrete in place of timber represent deviations from standard mining procedure.

It has been found that the limestone responds readily to this method of mining, breaking well upon the use of properly designed rounds in drifting and raising, shrinking uniformly throughout the entire length of the cut-off stopes whether driven vertically or inclined, and caving according to expectations.

A considerable part of the production is obtained from large material that descends during drawing operations. This large material requires no more drilling and blasting to reduce it to the required size than the material of intermediate size which must all be blockholed. A low-strength explosive used in this operation assists in keeping this cost at a minimum.

UNDERGROUND HAULAGE

Loading Chutes

Material is loaded from the storage raises into the cars from chutes on 25-foot centers. This distance was determined by the mining method rather than by the over-all length of the cars, because the trains are operated by a crew of two men with only one man available for loading. In more recent development, chutes are placed at 30-foot centers, which will allow for additional loading, if required, without movement of the haulage unit.

The chutes on the haulage level are built on 10- by 10-inch timbers placed in hitches and spanning the drift (see fig. 9). In general, the ground is massive enough so that posts under the stringers are not required. The chutes are double-sided and built of timber throughout, using 2- by 10-inch and 3- by 10-inch wooden gates for controlling the drawing. This type of loading chute is satisfactory for handling the sharp material obtained in the mine product. A steel arc-gate type of chute has been contemplated, but the strength required to prevent damage and to maintain it in operating condition, together with the first cost of the installation, appears to offset any promised advantage.

The drawing chutes on the haulage level are the only chutes used underground, control of the active stoping material being regulated by short 3- by 10-inch planks placed on the grizzlies themselves. The elimination of other chutes has assisted materially in the economic results obtained in stoping operations.

Electric-trolley haulage is used for transporting material from the loading chutes to the rotary tipple at the shaft. Hand tramming is only resorted to in development headings on the upper levels which are not directly accessible to transfer raises. No mechanical loaders or scrapers are used in connection with the mining method or transportation of material; neither have these machines been considered advantageous in connection with development work underground.

Cars

Production requirements from underground and the economic results desired governed to a great extent the design of the transportation equipment. Observations before underground mining indicated that limestone could be destructive to transportation equipment unless the latter was carefully designed, correctly constructed, and properly maintained. It was considered that the mobile equipment should contain a minimum number of parts subject to repair and replacement. The design of the cars included automatic, rotary couplers, thus obviating uncoupling cars during dumping and eliminating an accident hazard in this operation. A transportation unit of 1 locomotive and 14 cars, by this design, remains intact during production operations.

The cars are constructed of carbon-steel plates mounted on heat-treated axles provided with external, spring-mounted, journal boxes. The wheels are fitted with roller bearings. The cars have rotary-swing and swivel spring-mounted draft gear and bottoms of sandwich-type construction.

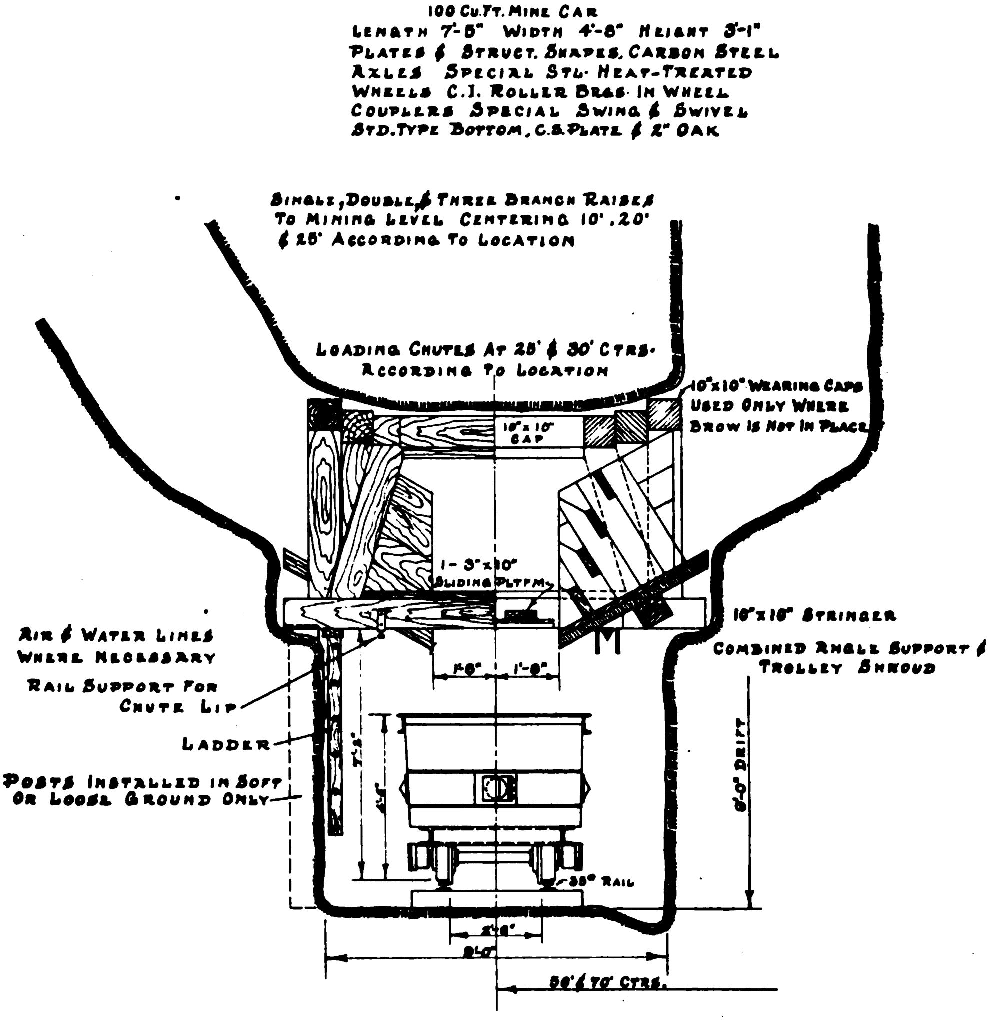

100 Cu.Ft. Mine Car
Length 7'-5" Width 4'-8" Height 3'-1"
Plates & Struct. Shapes, Carbon Steel
Axles Special Stl. Heat-Treated
Wheels C.I. Roller Brgs. In Wheel
Couplers Special Swing & Swivel
Std. Type Bottom, C.S. Plate & 2" Oak
Single, Double, & Three Branch Raises To Mining Level Centering 10', 20' & 25' According To Location
Loading Chutes At 25' & 30' Ctrs. According To Location
10"x10" Wearing Caps Used Only Where Brow Is Not In Place
10"x10" Cap
1 - 3"x10" Sliding Pltfm.
10"x10" Stringer
Combined Angle Support & Trolley Shroud
Air & Water Lines Where Necessary
Rail Support For Chute Lip
Ladder
Posts Installed In Soft Or Loose Ground Only
1'-6"
1'-6"
7'-2"
4'-5"
9'-0" Drift
35# Rail
2'-6"
9'-0"
60' & 70' Ctrs.

Figure 9
Pony Set. Loading Chutes, Mine Car, And Branched Raises.

0 2 4
Scale in feet

Original from THE OHIO STATE UNIVERSITY

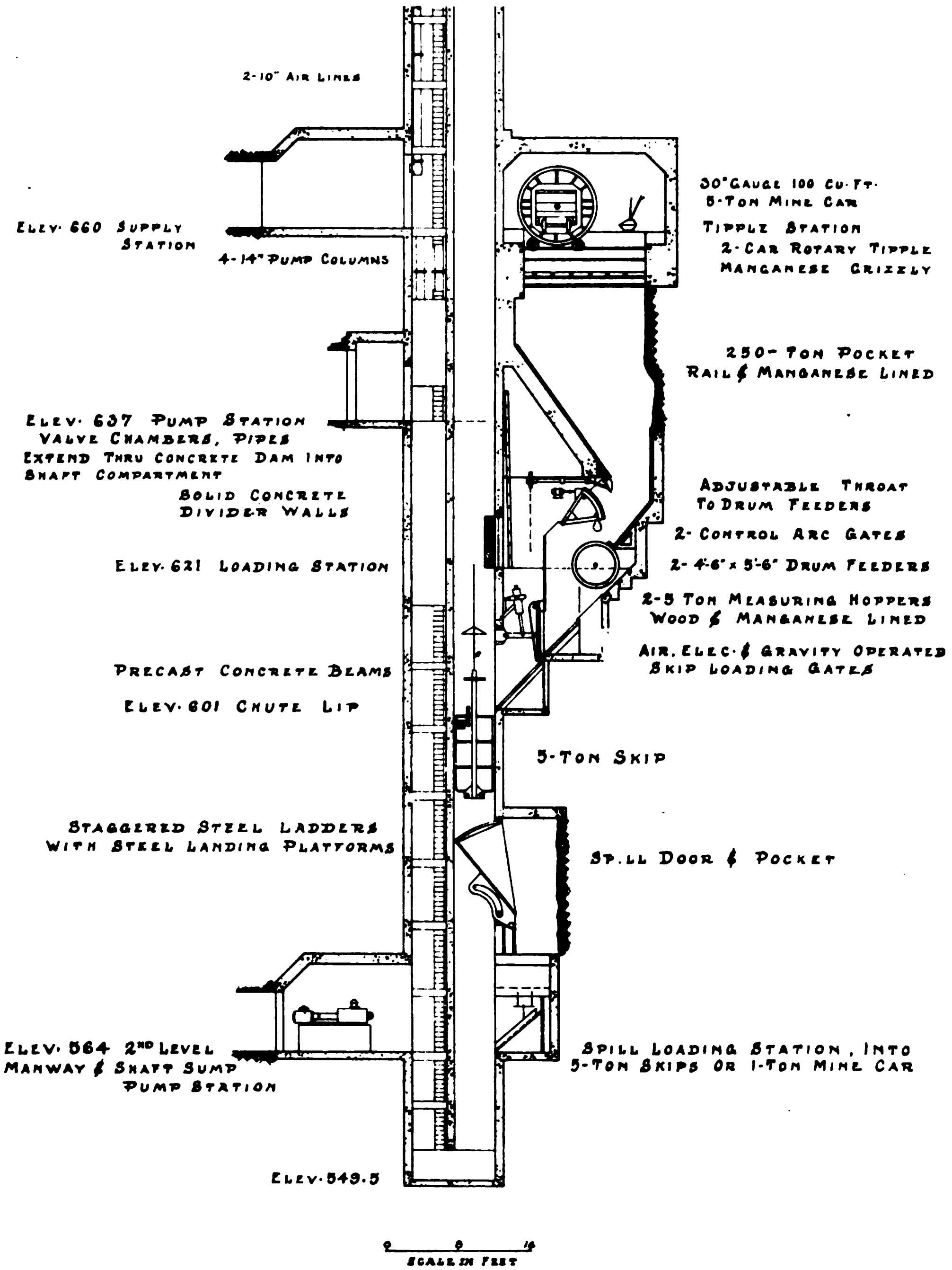


FIGURE 10. – MAIN SHAFT, LOADING STATION.

Locomotives

Six-ton electric-trolley locomotives with semimagnetic type of control, with two 30-hp. ball-bearing motors mounted between the frames and provided with special drawheads and couplers to connect the rotary coupler to the cars, are used for motive power. These locomotives are wired for series-parallel control and equipped with a protective device in case of accident to the motorman. An automobile-type horn is used on these machines for signaling.

Rotary Tipple

An electrically driven rotary car dumper of two-car capacity is located at the main shaft (see figs. 4 and 10) directly above the storage pocket. This equipment is provided with roller bearings throughout and revolves through 360° for a complete cycle of operation. It is equipped with clutch and brake mechanisms that allow the dumper to be stopped at any position in its rotation, thus allowing the large rocks to roll out of the cars onto the exposed portion of the grizzly, which is located immediately below the dumping mechanism. This grizzly removes material too large for the flow stream beyond this point. Oversize rocks are thus left in a convenient place for future handling.

Track

Single-track operation is provided throughout the major part of the haulage system. In the main haulage drift 45-pound rails with manganese-steel frogs are used, with 35-pound rails in the extraction sections. The transportation units of 1 locomotive and 14 cars are pulled from an extraction section, pushed on level track through the tipple without uncoupling, and returned to the drawing sections by a return drift which also connects with the man-material elevator. An annunciator system, with a simplified system of traffic signaling, is provided to assist operations on this level.

SKIP-LOADING DEVICES

The rotary car dumper is located over a 250-ton storage pocket designed to have 100 percent capacity. This pocket is excavated from the solid rock on the south side of the main shaft. In the bottom of the pocket are two openings from which the material is drawn by two electrically operated rotary drum feeders into the measuring hoppers. The two openings are lined with manganese steel on all four sides and provided with an adjustable side adjacent to the shaft, the action of which increases the area of the opening to facilitate breaking down any arching that may occur from boulders of excessive length meeting in these openings. The flow of material over the drum feeders is regulated by two electrically operated arc gates provided with heavy swinging hammers on their lower edge, thus allowing the passage of irregularly shaped material in the stream of rock as the drum feeder is operated. The measuring hoppers, which are below the loading-station floor, are designed to discharge directly into the hoisting skips and are in an excavation large enough to provide accessibility for repairs and maintenance.

The material in the measuring hoppers is discharged into the skips through a combined gravity-air-electric operated, flapper-type gate hung in a vertical position. The gate is similar to those used on the bottom of steam-shovel dippers.

All surfaces on this equipment subject to wear, from the bottom of the pocket to the discharge chute, are lined with manganese steel, with a sufficient thickness of timber between the manganese liners and the structural-steel frame to prevent distortion of the latter by the constant hammering from large material obtained in mining.

The excavations at the bottom of the pocket, loading station, and room for the measuring hoppers are concreted and have enough space for accessibility at all times.

The loading station is directly accessible from the elevator and is provided with labor-saving equipment for handling material in case of replacements. The chute lip in the shaft is reached by a ladder from the loading station; all connect with the manway in the main shaft. A ventilation fan, described later, assists materially in preventing a dust nuisance commonly found at these points in mining.

Material that leaks by the gates in the measuring-hopper pockets or past the skips during loading operations is deflected into auxiliary spill pockets by manganese-lined structural-steel doors directly below the skips. These doors are controlled by air-operated cylinders placed below the doors themselves. When closed, these doors allow the skips to descend as often as required for removal of this spill. Special means are provided at the spill loading station for handling this material in 1-ton mine cars on the man-material elevator to points of disposal, in case a condition arises that prevents the main skips from operating at this point.

All of the different parts of the equipment in this installation are electrically interlocked to prevent errors in operation.

HOISTING EQUIPMENT

The limestone is hoisted from the main shaft by a double-drum electric hoist large enough to lift from three extraction levels, if necessary, maintaining the same production from any level by a change in the size of the motor only and a consequent change in rope speed. The drums are 7 feet in diameter, with 5-foot faces grooved for a 1 1/4-inch rope. Both drums are loose on the main shaft and provided with oil-operated brakes and friction clutches of the axial-plate type. The hoisting speed from the present loading station is 600 feet per minute. All hoisting is done in balance and controlled by an operator on the hoist platform in the hoist house.

When hoisting from the present station and handling normal mine production, 60 skiploads or 300 tons per hour can be raised. However, when handling clay material, which is generally finer than the normal mine run, 400 tons per hour have been hoisted on several occasions.

Original from THE OHIO STATE UNIVERSITY

The hoisting equipment on the surface is housed in a steel and corrugated iron building, which also accommodates the motor-generator set for the underground haulage equipment and two 3,000-cubic foot air compressors. This building is provided with an overhead traveling crane.

The 120-cubic foot hoisting skips used in the main shaft hold a normal load of 5 tons, which is regulated by the size and design of the measuring hoppers. However, enough room is available in the skips for a slight overload if the same should occur. The skips are lined throughout with manganese steel mounted on wooden backing, with a special deflector plate on the top of the bail to prevent excessive hammering of large boulders on the side of the skip when in loading position. Roller-bearing trunnions are provided on the skips which are interchangeable with the stationary dump trunnions in the headframe. The dumping horns on these skips are laminated and provided with cast-steel, interchangeable, wearing surfaces. A minimum amount of clearance is allowed in the main shaft to provent serious damage to the shaft or equipment if abnormal conditions arise.

The headframe is of steel throughout and is equipped with manganese-steel-lined, 8-foot-diameter, plate-type head sheaves mounted on roller bearings in the hub of the wheels.

Equipment for Handling Men and Supplies

All men and material are handled by an automatic, self-leveling, traction-type elevator in the large compartment on the west side of the main shaft. The machinery for this elevator is mounted in the headframe itself at a sufficient height to allow the car to proceed above the collar of the shaft far enough for handling material of excess length. The platform of the elevator is large enough to handle the cars used for the haulage equipment. The locomotives, which are 17 feet 2 inches over-all without couplers, are lowered into the mine by suspending them below the bottom of the elevator. They are handled to this position by crane beams provided in the construction of the headframe.

Special doors, which are mechanically and electrically interlocked, are provided for all landings served by this automatic elevator. When the car is at rest at any landing, it unlocks the doors at that particular landing only. The doors are also interlocked with the controlequipment, preventing movement of the car unless all doors are closed and locked.

MINE DRAINAGE

The small amount of water made in normal mining is handled where convenient by auxiliary pumps on the different levels, or by draining to the sump at the bottom of the main shaft. There, 2 air-operated pumps are provided, 1 of the station type and 1 of the sinker type, the latter being movable if excessive water floods the sump at the bottom of the shaft. Water entering the limestone at the elevation of the sump drift is handled by electric pumps operating automatically. This water is excellent both as to chemical and organic content and is used for industrial purposes throughout the plant.

PERCENTAGE EXTRACTION

To date (1932), no drawing section underground has been completely mined, and therefore it is too early to express any opinion as to what percentage extraction of the limestone will be obtained. However, as it is necessary to include at least 10 percent of "clay" material to blend the limestone for manufacturing cement, there is every likelihood that extraction results will more than meet expectations. Records of production obtained to date indicate that a somewhat greater percentage of clean material has been drawn from the first block to be caved than is usual in this class of mining.

A difference exists between the mining of metallic ores and the extraction of material for manufacturing cement by the method under discussion. In most metal deposits mined by a caving method, all material may be included and extracted down to a point where the margin of profit ceases to exist. However, in manufacturing cement the limestone content must be of a certain value to allow the material to be used. If the material produced from a given section of the mine falls below the required calcium carbonate content it can be used only by the addition of clean limestone. Up to the present no material has been wasted or discarded from underground operations.

Judging from the work done to date it appears that each individual mining block has an economic rate of production beyond which an increase in drawing costs is marked. It also appears that this production can be more easily and economically obtained by uniform drawing over the total area available.

LABOR

No contract or bonus systems are in operation at present (1932). Good results are obtained by operating labor on routine work with fixed standards of accomplishment; and, in general, unit labor costs are satisfactory and comparative.

VENTILATION

Improvements made in underground mining include adequate ventilation in all working places. The necessity of maintaining good ventilation when limestone is mined is apparent, as the broken material readily absorbs and retains noxious gases from blasting. To meet this condition and maintain good ventilation a 33,000-cubic foot fan was placed on the surface over the top of the main ventilation raise connecting with all underground levels and exhausting from the mine. Intake air is obtained from the main shaft downcasting and from air entering through the caved ground, which is porous.

The mine development pursued to date has provided an ideal ventilation system without necessity of additional drifts or raises, as it has been found possible to incorporate in the development scheme all the ventilation features required for any part of the mine so far developed. The air is taken from the west side of the mine to the east, returning through the manway raises adjacent to the hanging wall to the upper levels, where it goes directly to the main ventilation raise and fan. Seasonal conditions affect underground venti-

Original from THE OHIO STATE UNIVERSITY

lation to some extent on account of the slight difference in elevation between the main points of intake and the main fan compared with the points of entry in the caved areas. To prevent this occurring in the remote mine workings auxiliary propeller-type fans are used, mainly to control the direction of the air rather than actually to create additional ventilation.

A small fan is placed at the tipple station to help maintain the main shaft as an intake. It provides efficient ventilation at the loading equipment at the pocket and assists in increasing the amount of air passing through the tipple station, thus preventing a dusty condition at that point.

As only a relatively small footage of the drifts used for ventilation are timbered the fire hazard is small; therefore, it is satisfactory to use wooden ventilation doors, mounted in wooden frames built in rubble-masonry walls. The rubble is composed of limestone or granite, according to accessibility. The manner of installation is such that the correct mine ventilation would not be interrupted if an underground fire should reach an underground door.

FIRE HAZARDS

The existence of a fire hazard in the underground workings is considered remote. However, its possibility has been given due consideration, and all main points of entry have been concreted and manway raises equipped with wooden stairs protected by sprinkler systems. Considerable concrete is used in place of timber in the mine workings, reducing the quantity of timber underground.

The underground water system is so laid out and interconnected as to prevent loss of water at any remote location due to line failure in any section. Ample pressure is maintained for fire fighting if necessary.

The underground powder magazine is of concrete and steel construction throughout, concrete bins being provided for any explosive opened during the operating shift. This magazine is provided with fire extinguishers and water hose coupled for immediate use.

A fully equipped mine rescue-station is maintained.

SAFETY METHODS AND FIRST AID

Since mining operations were begun, accident prevention has been a major point of consideration, and all men employed underground have been made to understand that the prevention of accidents is important. Supervisory personnel is especially instructed that preventing accidents is part of their duties. With the system in force, the necessity and expense of special employes for this purpose have been eliminated, with results that appear to be an improvement over what has hitherto been considered standard practice.

All men working underground are equipped with goggles, safety hats, and safety shoes, the latter being found more advantageous than other auxiliary means of foot protection. A small bonus is paid each man if the division in which he is employed operates a full month without any lost-time accidents. All men in charge of labor carry first-aid kits when proceeding to work. These kits are stored in accessible locations during the shift. Enough of these kits are underground at all times to avoid the necessity of men proceeding to first-aid lockers to receive dressings. An ample number of men in all parts of the mine are trained in first-aid work. A well-equipped first-aid station is also maintained on the surface, with additional material, supplies, and resuscitation equipment. Hospital facilities are conveniently located and are reached by rapid ambulance service available at all times. The ambulance is accompanied by a doctor when necessary.

ORGANIZATION

In adapting this system of mining, heretofore used only by large producers, to the more limited capacity described in this paper, it was necessary to build an organization with a minimum personnel not directly connected with production. This organization was built to function as a complete unit rather than as individual units operating under separate departmental control. All operations at the cement plant are under the supervision of a general superintendent. The mine organization is responsible to him for maintaining the required production for the mill. A mine superintendent, who has an assistant capable of caring for detail work, is directly responsible for the mining operation. All underground work is under the supervision of a mine foreman. Further divisions into departments are not made, as all personnel below this point actually performs part of the daily work necessary for maintaining production. Although the organization appears small, complete engineering, clerical, and cost records are maintained; only the accounting reports necessary for mining operations are compiled at the head office of the company. This organization has functioned long enough to have proved adequate for the scale of operations conducted.

MINING COSTS

The method of cost accounting adopted was such that after the mine had progressed beyond the development period and reached the flexibility of operations required for maintaining a uniform production, cost figures would be available that were comparable with other mining operations pursuing similar methods.

The development work was commenced in such time that the mine would be on a producing basis in approximately 2 1/2 years. However, as additional development was continued up and through 1931 to increase the broken-rock reserves, expenditures during 1931 were slightly higher than would be required for normal operations. The figures for 1931 therefore would not represent average production costs. This is shown by the following table covering the percentage of material produced, by the various classes of underground operations.

	Percentage of total production		
	Since inception	1931	Estimated normal
Development	16.62	8.88	2.17
Mining	19.91	15.16	8.84
Production	63.47	75.96	88.99
Total	100.00	100.00	100.00

Representative statistics of the mining operations will be available only when market conditions allow production to approach the estimated normal requirements of the cement plant.

Such underground costs as have been established by direct operations are included in the following tabulations.

The following table shows the cost of drifting, raising, and timbering in connection with the development of 1,258,379 tons, and the cost of cut-off stoping, undercutting, raising, and extraction during active mining of 1,775,696 tons.

Cost per ton of development and active mining

Cost per ton	Labor	Timber	Explosives	Power and Miscellaneous	Total
Development	$0.0374	$0.0062	$0.0165	$0.0044	$0.0645
Active mining	.0706	.0051	.0400	.0110	.1267

The following table shows normal production costs, based upon operations during 1931, and is considered to be fairly representative of results obtainable by this method of underground operations.

Production costs per ton hoisted

	Labor	Timber	Explosives	Power and miscellaneous	Total
Drawing	$0.0939	$0.0081	$0.0269	$0.0054	$0.1343
Haulage and hoisting	.0392	.0002	.0004	.0060	.0458
General underground expense	.0254	.0004	--	.0092	.0350
General mine expense	.0176	--	--	.0023	.0199
Totals	.1761	.0087	.0273	.0229	.2350
Hanging-wall rock	--	--	--	--	.0132
Total	--	--	--	--	.2482

In the preceding costs, general underground expense covers expenditures in connection with mine supervision, mine illuminants, man hoist, change house, ventilation, mine tools, and mine drainage; and general mine expense covers expenditures for the mine office, warehouse, engineering, framing shed, and general supervision pertaining directly to underground operations.

The following table for 1932 shows production costs more closely approaching normal conditions than those covering the early stages of operation.

Summary of costs in units of labor and supplies

Year	Tons per man-shift Mining	Tons per man-shift All employees	Pounds of explosives per ton	Board feet of lumber per ton	Kilowatt-hours per ton
1932	17.3391	15.8970	0.5187	0.7509	4.3407